Efficient Endmember Detection onboard the EO-1 Spacecraft

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Agenda

Why analyze spectra onboard?

The EO-1 spacecraft

Algorithms

Adapting to Flight

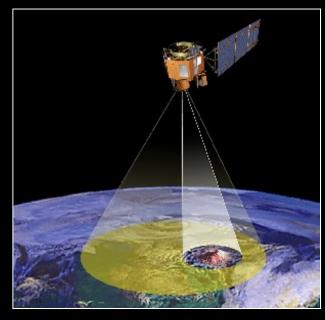
Planned Observations

Discussion, Questions?



Why bother with onboard analysis?

- Communications are intermittent and bandwidth constrained
- Onboard analysis can recognize target features for high-resolution data acquisition, followup measurements
- Provides onboard data summary for efficient downlink
- Particularly important for highvolume hyperspectral images
- Endmember detection helps when targets aren't known in advance



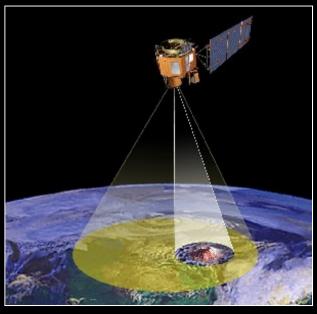
EO-1 Selective downlink of volcanic activity "hot spot" in thermal imagery (Chien et al. 2005)



EO-1 Experiment goals

- Demonstrate techniques for onboard hyperspectral image analysis
 - Segmentation
 - Feature detection
 - Endmember detection
- Motivate efficiency improvements for onboard algorithms
- Show fully-unsupervised anomaly discovery and scene summary
- Explore performance for Earth science and commercial application domains

6/4/2012



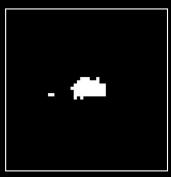
EO-1 Selective downlink of volcanic activity "hot spot" in thermal imagery (Chien et al. 2005)



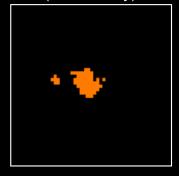
The EO-1 Spacecraft

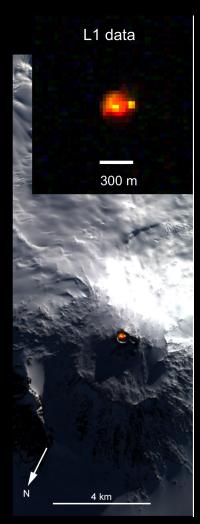
- Used in sensorweb and autonomous science operations since 2004
- Currently in an "extended mission" phase
- Detects transient events such as floods and volcanoes
- Mongoose-V 32-bit microprocessor for onboard data analysis
 - 12MHz clock speed
 - No hardware floating-point arithmetic
 - Limited Memory

7 May 2004: ASE Thermal Classifier Thumbnail (Erebus Night)



7 May 2004: ASE Thermal Classifier (Erebus Day)







Approach

Image acquisition

Optimal band selection, observation sequencing (offboard)

Initial preprocessing for noise reduction

Superpixel segmentation finds features

Downlink full spectra of the detections

Endmember detection in features



The Hyperion hyperspectral imager

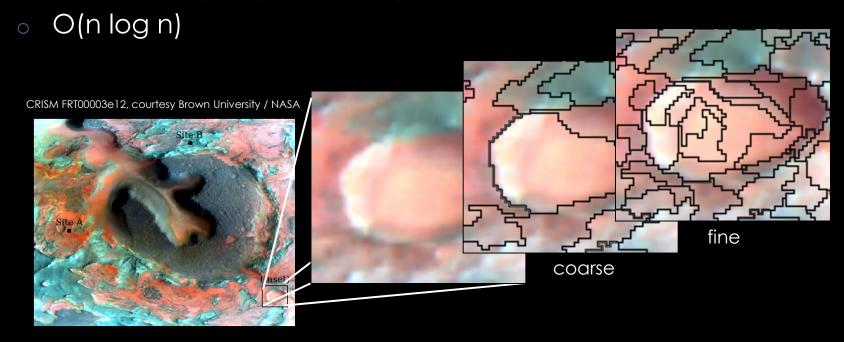


Hyperion view of Cuprite, NV

- High resolution hyperspectral imager
- 220 spectral bands from 0.4 to 2.5 µm in
- 30 meter spatial resolution, provides 7.5 km by 100 km land area per image
- A reflectance product is available for onboard use
 - 12 bands selected in advance (once per observation)
 - 256x1024 pixel subframe

Superpixel segmentation

- Find spatially contiguous, homogeneous regions corresponding to physical features
- Reduces runtime, memory of later processing by 10-100x
- Users specify appropriate spatial scale

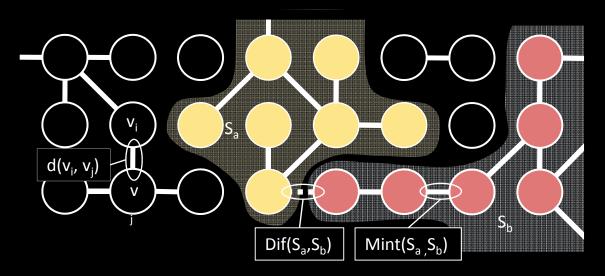




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Superpixel segmentation

- A graph partitioning algorithm [Felzenszwalb 2004] oversegments the image
- Compute spectral distances between neighbors
- Agglomerative clustering iteratively connects segments by growing minimum spanning trees





Superpixel segmentation

2.5

superpixel average A superpixel's spectrum is the 0.16 mean of the component pixels 0.15 0.14 preprocessing with 0.13 spectral median filter 0.12 0.17 0.11 0.16 1.2 1.4 1.6 1.8 2.0 2.2 2.4 Wavelength 0.15 0.14 0.13 initial CRISM spectrum (NASA/Brown) 0.12 0.17 1.2 1.4 1.6 1.8 2.0 2.2 2.4 Wavelength 0.16 0.15 Value Yields theoretical noise 0.14 0.13 improvement of order 0.12

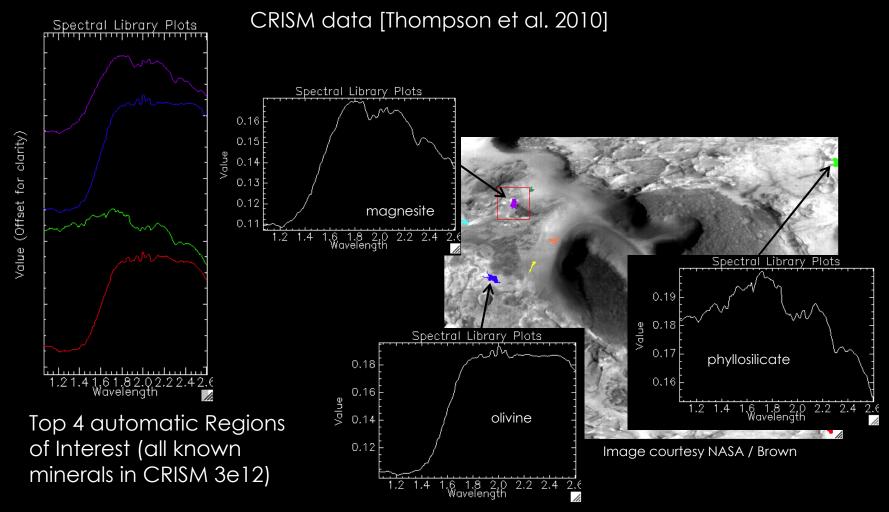


0.11

 $n^{1/2}$ for a superpixel of

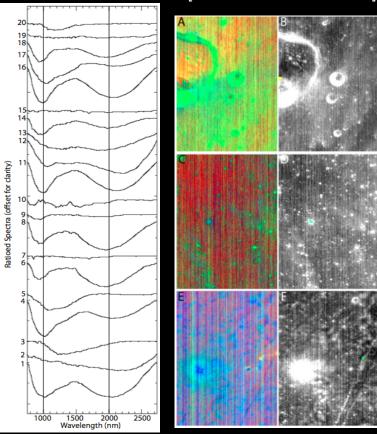
size n

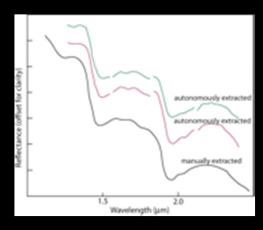
1.5 2.0 Wavelength

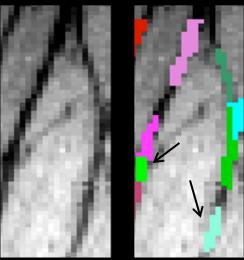




Mafics in M3 Lunar data [Gilmore et. al., 2011]





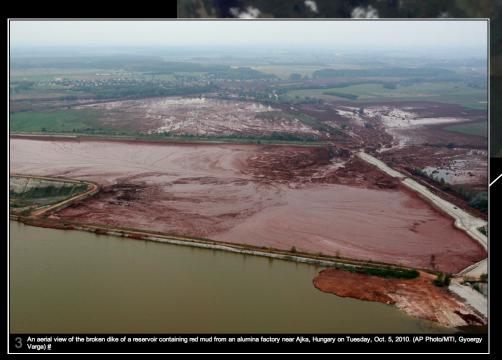


Low-spatial-resolution NIMS features showing ices, possible amides on Europa [Bunte et al. 2011]



High concentration of sludge

Kolontar toxic sludge spill Hyperion ALI (9 bands)



Hyperion ALI image (courtesy NASA/GSFC)

TEXT: BOSTON GLOBE; IMAGE: AP



Sulfur outflow at Borup Fijord is a candidate for onboard detection due to astrobiology implications(Mandrake et al. 2009)

Here it is detected automatically in Hyperion

images



Helicopter photo showing sulfur outflow (courtesy NASA)



spectral angle map



Original hyperion image



Adapting to Flight

- SMACC algorithm [Gruninger 2004] favored for speed, computational simplicity, test set performance
- Segmentation reduces number of spectra from ~10⁵ to ~10³
 - Trades for an O(n log n) segmentation for polynomial time endmember detection
- In practice, edge weight computations are a bottleneck
- Max. memory usage is just 15MB

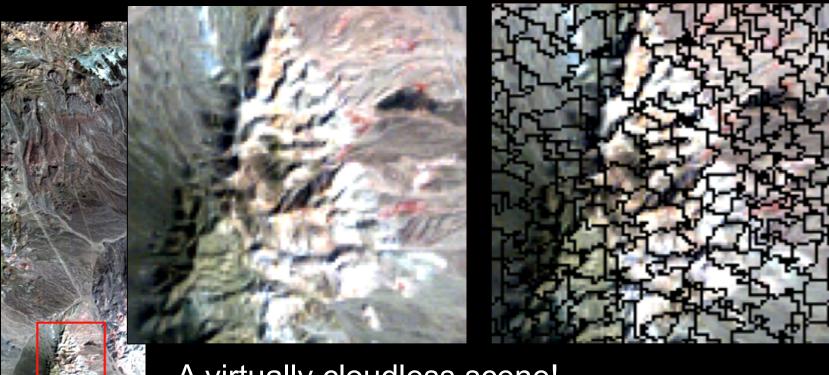


Adapting to Flight

- Full unit test coverage of all code
- Regression test suite for performance evaluations
- Validation on lab testbed



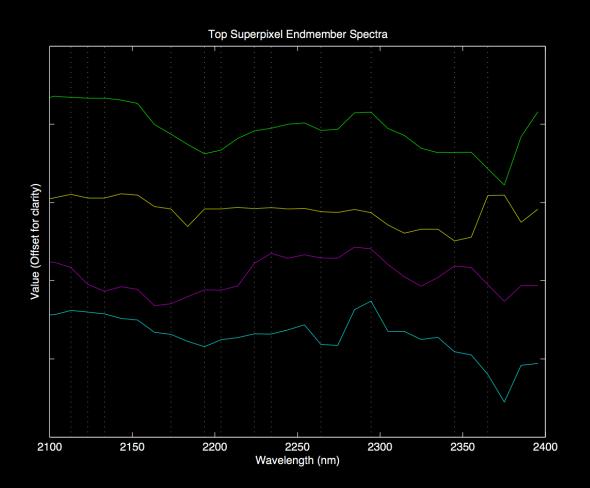
Cuprite overflight test

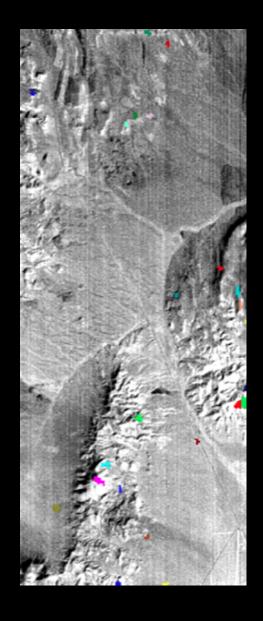


A virtually cloudless scene!
Targeting successful; most of the classic
Cuprite scene is visible



Cuprite overflight test







Next steps

June-July 2011 Integration

August 2011 Software Upload

 Summer 2011 Software checkout procedure

 Summer 2011 Flight demo of onboard processing

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Possible targets

Cuprite, NV (for repeatability)

 Borup Fijord, Canada (astrobiology implications for Europa)

[Your ideas!]



Thanks!



